Reply to second comment from referee #2

This referee appreciates the conundrum faced by the authors and agrees that in the future, investigators should strive to provide in-situ studies that image ice particles with optical probes alongside lidar measurements of depolarization ratio (for the same portion of cloud) that could validate the categorization of ice particle shapes remotely. However, after delving further into the Voronoi literature, there appear to be two issues that require clarification regarding the use of the Voronoi ice particle shape in this and other studies: (1) what is the characteristic shape of a Voronoi ice particle and (2) how representative are these shapes in natural ice clouds? These two issues will now be addressed.

Regarding (1), the Voronoi ice particle was first conceived by Ishimoto et al. (2012, JQSRT) and it follows a mass-dimensional power law that is consistent with that derived from the composite dataset of measured ice particles reported in Heymsfield et al. (2010, JAS). These model-generated fractal particles consist of seven aggregates and their images are shown Fig. 3 of Ishimoto et al. (2012). While this study emphasizes that these model ice particles represent aggregates of ice crystals, they may arguably represent any complex ice particle shape for the purpose of modeling the single scattering properties of cirrus cloud ice particles. Such an argument was made by Macke (1993, Appl. Opt.) and Mitchell et al. (1996, JAS).

Regarding (2), examples of irregular or complex ice particle shapes in tropical cirrus clouds are shown in Fig. 5 of Woods et al. (2018, JGR) for both “large irregulars” and “small irregulars”. Figure 10 of Woods et al. shows the percentage of various ice particle shapes as a function of temperature in terms of number concentration, area, and mass. Between -40 °C and -60 °C, the percentage of small and large irregulars ranges from ~ 60% to ~ 70% based on number concentration. However, neither the small nor large irregulars resemble the Voronoi aggregates, other than they share a complex structure. For temperatures between -60 °C and -90 °C, Fig. 10 in Woods et al. shows the percentage of spheroids (often parameterized as droxtals when modeling their optical properties) range from ~ 55% to ~ 73% based on number concentration, respectively. Images of spheroids are also shown in Fig. 5 of Woods et al. (2018, JGR). This colder region is known as the tropical tropopause layer (TTL) while the warmer region is characterized by anvil cirrus (e.g., Gasparini et al., 2017, J. Climate). Results similar to those in Woods et al. (2018) are reported in Lawson et al. (2019, JGR). Voronoi-type shapes are featured in this Lawson et al. study in continental anvil cirrus where electrical fields are stronger, as illustrated in Fig. 9 and 12 of this article.

The above points need to be mentioned in the submitted paper by Noel et al. This referee suggests arguing that the Voronoi aggregates, although having shapes not representative of irregular ice particles found in natural tropical cirrus clouds, may capture the scattering properties of these irregular ice crystals due to their complexity (which also affects surface roughness which is known to affect the phase function).

The new Fig. 1 shows Voronoi aggregates strongly dominating the field of cirrus clouds (even at the highest altitudes), which seems very unlikely if their shape is taken seriously, but plausible if Voronoi aggregates are only a proxy for irregular ice particles in terms of their single scattering properties.

We understand and appreciate the reviewer's desire to clarify the point of Voronoi particle shapes, since these shapes do not seem to match the shape of most ice crystals as documented by in-situ measurements. We thank the referee for creating an opportunity to discuss this issue, which to our knowledge has not yet been explicitly addressed in the literature.

In response to this comment, we have updated the text (Sect. 2.2 and 3.1) to include a discussion of Voronoi particles, the fact that their shape is not representative of most ice crystal shapes as documented by in-situ measurements, and that they however still can capture the scattering properties of a particular subset of ice crystals characterized by structure complexity. We base this discussion on most of the references suggested above.